IMPLEMENTATION OF A PRECISION LOGARITHMIC AMMETER

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Abstract

A precision ammeter is in development for the acquisition of sensor signals such as photodiodes, gold mesh (by photoelectron effect) and ionization chambers. One of the problems of conventional ammeters is the automatic scale selection, which hinders many measurements performed in ample energy ranges. The ammeter in development is based on a different methodology than present on most commercial systems, using a logarithmic amplifier. This choice can provide a logarithmic response output in the range of pico to milli-amperes. The electronic board is in development by Brazilian Synchrotron Light Laboratory (LNLS), and it is being installed and tested at the Toroidal Grating Monochromator (TGM) Beamline.

BASIC OF LOGARITHMIC AMPLIFIER

A logarithmic amplifier (LogAmp) is a device that can express the output as a logarithmic function of the input, either in electrical current or voltage. This device is commonly used in telecommunications for compression of voice and video signals, and here it is explored its potential for measuring and monitoring currents produced in light sensors. [1]

The most common LogAmp uses the exponential curve of a bipolar junction transistor (BJT) to convert an input current in a logarithmic output voltage. This class of LogAmp usually operates on unipolar inputs and it is very sensitive to temperature variations. The most simplified model is composed by a NPN transistor connected at the negative feedback of an operational amplifier, as shown outlined in Figure 1. The transfer function of this circuit is:

$$V_{out1} = -V_{BE} \approx Vt \ln\left(\frac{I_{IN}}{I_s}\right) \tag{1}$$

Where I_s is the reverse saturation current and V_t is the thermal voltage. The first is a constant dependent of the construction parameters, materials, and, as consequence, temperature of operation. The thermal voltage is a universal parameter of transistors, and depends only on the temperature. The approximation shown above can be used due to the fact that the input current in the OpAmp is approximately zero.

A first solution to reduce the dependence of temperature is introducing a second LogAmp, which acts like a reference to the first through a subtracting circuit, as shown in the Figure 1.

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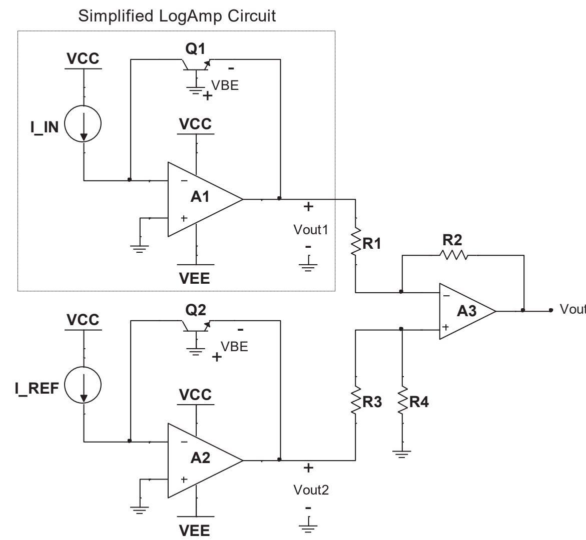

Figure 1: A referenced current LogAmp is shown above. A simplified model of a LogAmp circuit is outlined. The subtraction of two simple LogAmps with the third OpAmp (A3) eliminates the temperature dependence generated by I_s.

The general transfer function of the above circuit is given by:

$$V_{out} = V_{LOG} = V'_y \ln\left(\frac{I_{IN}}{I_s}\right) - V'_y \ln\left(\frac{I_{REF}}{I_s}\right)$$

$$V_{LOG} = V_y \log\left(\frac{I_{IN}}{I_Z}\right) \tag{2}$$

Where V_y is a function of V_t and the gain attributed of the resistor in the subtractor circuit, and I_z is a conversion name to I_{ref}. This approach is able to eliminate the temperature dependence caused by I_s because the transistors have the almost identical properties and are in close thermal contact for proper cancellation. However, V_y is proportional to V_t, and so, it is still sensitive to temperature variations. By adding subsequent temperature-compensation circuitry this dependency is virtually eliminated (normally, an additional OpAmp amplifier stage with a resistive temperature detector [RTD], or similar device, is incorporated as part of the gain) [1]. Several commercial integrated circuits have embedded some type of temperature compensation which can stabilize the final gain V_y of the system.

DEVELOPMENT OF THE CONCEPT

For the development of the Logarithmic Ammeter (Log-Ammeter), it was designed an electronic based on a commercial LogAmp IC, with a range of 200 dB. This circuit has an internal reference current of 100 nA and a temperature stabilizing embedded in the chip. The system

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was designed to produce an output voltage from -1 V to 1 V for an input from 1 pA to 10 mA. To elaborated all the tests, it was used an experimental setup like depicted on Figure 2.

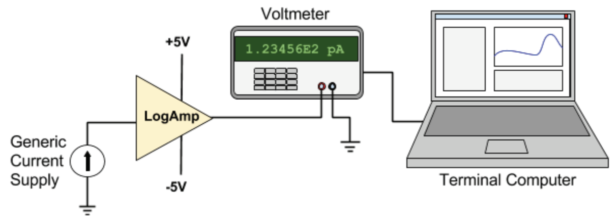

Figure 2: Schematic of the experimental setup for LogAmp tests. All of the experiments were developed in this configuration. The communication between the Terminal Computer and the Voltmeter is made by the IOCs from the EPICS system. The Generic Current Supply can be any device; a commercial supply, a photodiode or a voltage power supply in series with output resistors.

First it was necessary to characterize the experimental parameters V_y and I_z. Utilizing a Femtoamp Remote Sourcemeter 6430 from Keithley as a current supply, it was possible obtain the curve I-to-V characteristic of the LogAmp (Figure 3). Manipulating the Eq. (2), it was obtained the linear relation:

$$V_{LOG} = A\ \log(I_Z) + B \tag{3}$$

Where A = V_y and B = -V_y.log(I_z). Then, varying the input current of the LogAmp, it was obtained the curve presented on Figure 3. From its, determine the parameters $V_y = (0.2015 \pm 0.0006)$ V/decade and $I_z = (115 \pm 8)$ nA could be determined.

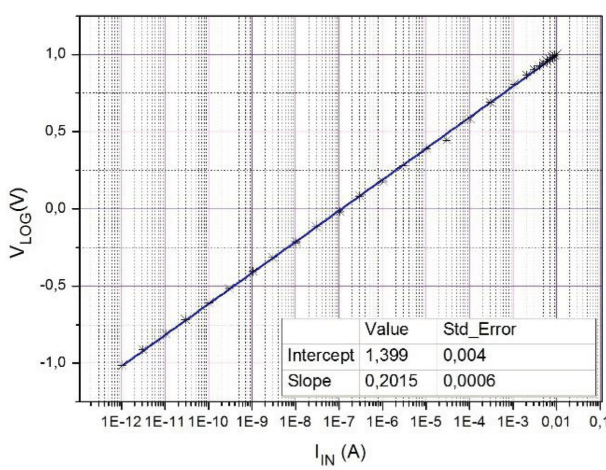

Figure 3: Relation IIN-to-VLOG of the LogAmp. The slope value corresponds to the parameter V_y, and from the Eq. (3), $I_z = (115 \pm 8)$ nA.

After this characterization by a controlled input current, it was possible to determine a calibration equation of the LogAmp, and so, monitoring currents from other experiments. For the next steps of the tests, it will be assumed the absolute values from the parameters, V_y = 0.2015 V/decade and I_z = 115 nA.

TESTS MADE AT THE TGM BEAMLINE

Initially, the proposed to create a logarithmic amplifier is for the use in the beamlines in the Brazilian Synchrotron Light Laboratory (LNLS). The second part of the experiments consists in make tests at the Toroidal Grating Monochromator (TGM) Beamline using the LogAmp with the aim to validate the technique.

The TGM beamline operates in the Vacuum-Ultraviolet (VUV) energy range, from 3 eV to 330 eV through three grades [2]. The present results were performed by the grade 1 (3 eV to 13 eV).

Energy Scan

A basic test of the TGM Beamline is a scan varying the energy on the monochromator. The monochromatic synchrotron radiation focuses on a diagnostic photodiode and energy is changed by moving the diffraction grating, producing a characteristic profile of the response of photodiode/efficiency of the grating. For this test, the current supply was replaced by the diagnostic photodiode. The values of energy and voltage were registered by the terminal computer from Experimental Physics and Industrial Control System (EPICS). A datasheet was created. It was compared the performance of the LogAmp and a commercial ammeter normally used on the beamline. For each instrument, fifteen scans were recorded and it was made the average of the curves. The results are shown in the Figure 4.

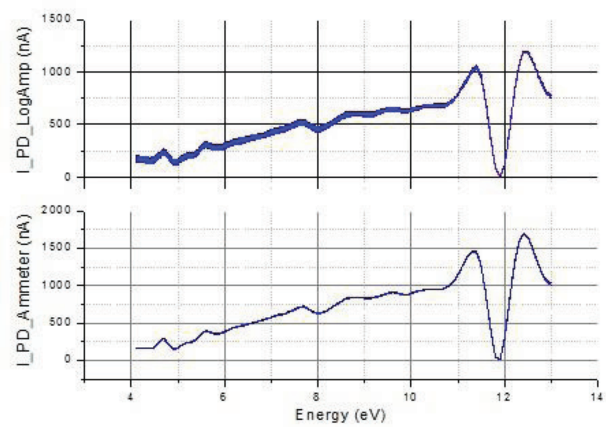

Figure 4: Energy scan for the 1st grating (3 eV to 13 eV). Each graph refers to the average curve of an instrument with standard error. The upper curve is the profile obtained by the use of the LogAmp, while the lower curve was obtained by the commercial ammeter.

From Figure 4 it is possible to see that the curve obtained from the LogAmp has a profile many similar to the obtained from the commercial ammeter. The noise, although small, present in the graph is due to the absence of any kind of filter in the input, which can make appear some fluctuations in the measured current. A difference of the values observed in the two curves occur because the curves was obtained for different alignments of beamline and ring current.

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Total Electron Yield

After the scans in energy, the LogAmp system was used to measure a standard sample of TGM Beamline, to prove its concept in a real experiment. The Total Electron Yield (TEY) is a system that allows the indirect measure the absorbed photon flux as a function of its energy by measuring the reposition current driven to the sample after photoelectrons ejection when hit by the incident VUV and X-ray beam [3]. A current is generated on the sample holder and it is measured in an ammeter. An aluminum foil was fixed at the sample holder and the energy was varied like in the previously scan. Like the energy scan test, it was made TEY scans for a commercial ammeter and the LogAmp. Were realized seven scans for each instrument. The average curves are shown in the Figure 5.

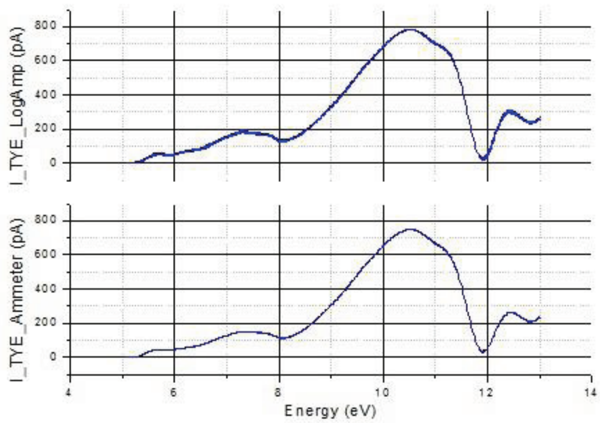

Figure 5: TEY scans for the grating 1 (3 eV to 13 eV). Each graph refers to the average curve of an instrument with standard errors. The upper curve is the profile obtained by the use of the LogAmp, while the low curve was obtained by the commercial ammeter.

For the TEY tests, it is possible to see that the values obtained is more precisely than the other case. The profile of the curves is practically the same, and the small difference between the curves are caused by a natural misalignment of the beamline and the decrease of the current in the storage ring. The TEY test is important to show how efficiently is the LogAmp in the picoampere range.

Motor Alignment

The last test realized at TGM Beamline intended to show how the LogAmp can cover a large range of currents without changing its scale. This test consists of use the LogAmp to monitor the signal in the diagnostic photodiode when the position of the first mirror is varied. The Figure 6 shows the current in the photodiode as a function of the motor position.

This graph shows the capacity of the LogAmp to vary 7 decades without change the scale of measurement. This property is really interesting because one of the mainly problem of the commercial ammeters is the switch time between two scales of measure.

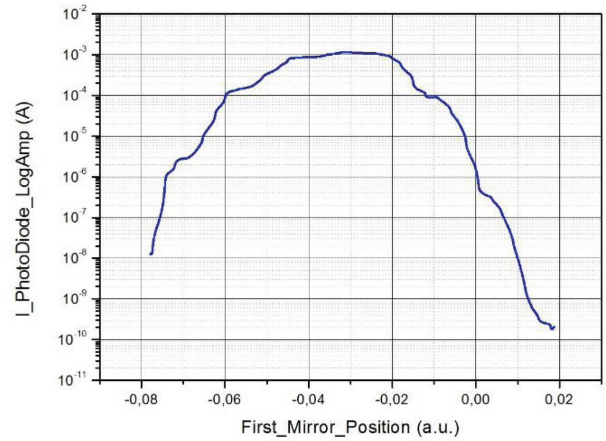

Figure 6: Current in the photodiode in function of the zenithal position of the first mirror. The first mirror position has an arbitrary unit.

CONCLUSION

The use of a logarithmic amplifier proved to be a good option to current measurements. The motor control test shows the capacity of very large range of currents without the necessity of change the scale. This is an advantage of the LogAmp when compared to other types of ammeters, which would allow the detection of events which vary the measured value some decades. The energy scans performed at the TGM Beamline show the performance of the LogAmp in a real experiment, proving the capacity, usability and efficiency of the LogAmp to be used at beamlines, even for measuring very low currents on real experiments of photo-absorption.

Simultaneously to the development of the LogAmp, it was implemented an algorithm of an Analog Digital Converter (ADC) to convert the output voltage of LogAmp in a digital current measure. The chosen ADC is in a Field-programmable gate array (FPGA) which contains a fourth order Σ-Δ modulator of 24-bits resolution for high precision measurement applications, with analog input in bipolar operation. The FPGA will be used to implement data transmission over Ethernet interface with EPICS driver. It will have a trigger input for synchronism with external events which allows to do measure as Fly-Scan [4], for example. Operation tests were proceeded with the ADC powered by a voltage source and also a rapid test of integrating ADC and LogAmp, both were successful.

The next steps in the development is the study filter design to stabilize the signals in the LogAmp, and the integration of amplifier and ADC and the with the terminal computer directly [5].

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